Arterial Line Placement

Safety First

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ARTERIAL lines are regularly inserted in patients in the perioperative and critical care setting to measure hemodynamic variables, such as beat-to-beat blood pressure and cardiac output, and to regularly obtain blood gas values and other measurements from plasma. In the research setting, arterial lines are occasionally inserted for measurements that cannot be obtained from other sources. For example, arterial samples are often more valuable than venous samples in the pharmacokinetic–pharmacodynamic modeling studies.[1] In this issue of Anesthesiology, Nuttall *et al.*[2] describe the possible risk factors related to severe arterial line complications in adult patients undergoing a large variety of surgical procedures. They report on more than 62,000 arterial lines placed in more than 57,000 patients in a 7-yr period (2006 to 2012) at Mayo Clinic in Rochester, Minnesota. For almost 56,000 times, the catheter was placed in the radial artery. The authors detected a severe complication rate in a small minority of patients ranging from 2.7 to 12.3 per 10,000 patients depending on the location of the arterial line. On average 8 per 10,000 patients developed a serious complication. The data indicate that arterial line placement has a low complication rate, and consequently we feel confident to state that arterial line placement, when performed by qualified personnel, is a safe medical procedure.

"In healthy volunteers, the placement of an arterial line should be carefully weighed between the scientific benefit ... and the possible complications."

Focusing on the radial artery, which in clinical and research settings is the most common site of arterial line placement, Nuttall *et al.* reported on just 15 cases with a severe complication. Most frequent complications were related to thrombotic occlusion of the radial, ulnar, and/or brachial arteries or vasospasm, leading to symptoms in the affected hand that included lost radial pulse, pain, numbness, paresthesia, cool mottled skin, and local cyanosis. Additional complications included neuropathy due to nerve damage, bleeding, and pseudoaneurysm formation. It is important to realize that in eight cases, no intervention was required as symptoms resolved spontaneously.

It seems surprising that cannulation of the radial artery, a vessel just 2.5 to 5 mm in diameter,[3] does not lead more frequently to serious complications. This is especially true when realizing that asymptomatic temporary occlusion of the radial artery on cannulation is quite common and occurs in up to 35% of patients.[4] This is partly related to the collateral circulation in the hand. The radial ulnar arteries are connected through deep and superficial palmar arches from which digital arterial branches perfuse the digits.[3] Consequently, adequate reserve in perfusion is available when one of the arteries becomes occluded. Some variation in the anatomy of the palmar arches is evidently present with an incomplete superficial arch in 16% of patients; the anatomy of the deep arch is much less variable, and an intact arch may be assumed in most patients.[3] In addition, recruitment of nonfunctional capillaries and new capillary formation in response to tissue hypoxia from prolonged and possibly even acute vessel occlusion may occur.[5] The safety of radial artery cannulation is further confirmed by data from children and the large body of evidence from the cardiology literature.[5,6] Already in 1987, Selldén *et al.*[5] showed safety of long-term placement of a 22-gauge (0.8 mm) radial arterial catheter in children and neonates admitted to the intensive care unit

Image: J. P. Rathmell.

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Accepted for publication October 29, 2015. From the Departments of Anesthesiology (A.D., M.N.) and Health Care Ethics (D.P.E.), Leiden University Medical Center, Leiden, The Netherlands.

 Anesthesiology 2016; 124:528-9

or operating room. The cardiology data show that coronary angiography and coronary intervention (such a coronary stent placement) using the transradial access is considered safe with ischemic complications rarely reported.[6] The occurrence of severe complications, as described by Nuttall *et al.*[1] and others,[6] may be explained by embolization from the primary thrombus causing occlusion of end arteries.

Most anesthesiologists and cardiologists apply the Allen test to assess the vascular patency of the hand before cannulation of the radial artery.[7] The Allen test is simple: The patients make a fist, after which both ulnar and radial arteries are occluded. The hand is then reopened and appears white (pallor). The release of pressure on the ulnar artery should lead within 15 to 20 s to hyperemia of the skin. A positive result of the test is that pallor persists, suggestive of the absence of collaterals between the radial and the ulnar arteries. Given the above, it seems reasonable to question whether the Allen test is sufficiently sensitive in predicting vascular patency and complications after radial artery placement. McGregor[8] showed in 1987 that in six patients with a positive Allen test, dye injected *via* the radial artery spread through the entire hand on ulnar artery occlusion, whereas initially it was retained to the thumb and thenar eminence. The author concluded that the Allen test is "of no clinical value." In a recent discussion article, Shah *et al.*[6] make a convincing case for the limited value of the Allen test or the adaptation of the test in which digital plethysmography is used as a monitor of vascular patency. One of the studies they discuss is from Valgimigli *et al.*[9] who showed that patients with a positive Allen test display signs of enhanced collateral perfusion originating from the ulnar artery after radial artery cannulation.

So far we discussed radial artery placement in patients undergoing surgical or cardiological procedures. The first studies that report on arterial catheter insertions in healthy volunteers date from the late 1970s and early 1980s. Also in our clinical research unit, we regularly insert 22-gauge arterial lines in the radial artery of healthy volunteers involved in hemodynamic or pharmacological studies. Since the year 2000, we placed 980 arterial lines in 895 volunteers. Before starting, the procedure was comprehensively discussed with the institutional review board (IRB). The IRB granted permission and stipulated scrupulous monitoring, including questionnaires to be filled in by the research subjects and periodical reporting to the IRB. Evidently, the risk–benefit consideration of an arterial line in healthy subjects is not comparable with the considerations made in relatively sick patients undergoing often complex surgeries with possibly hemodynamic instability. In healthy volunteers, the placement of an arterial line should be carefully weighed between the scientific benefit (*e.g.*, the harvesting of rich data collected from beat-to-beat hemodynamic measurements or frequent drug samples from plasma) and the possible complications. The data from Nuttall *et al.* certainly help in this respect. Their observation of a low complication rate is mirrored by our own observations. In the 15 yr that we insert arterial lines in volunteers, we observed one complication: the formation of a painful pseudoaneurysm in a 22-yr-old female subject, which resolved spontaneously within weeks without residual complaints. If the research benefits of arterial catheterization in healthy volunteers are considerable, it would appear that they are well worth the very small risks of this medical procedure.

Competing Interests

The authors are not supported by, nor maintain any financial interest in, any commercial activity that may be associated with the topic of this article.

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Surgical and Patient Risk Factors for Severe Arterial Line Complications in Adults

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ABSTRACT

Background: Prior research has provided inconsistent data regarding the risk factors associated with complications from arterial cannulation. The goal of this study was to clearly define the incidence and risks factors associated with arterial cannulation complications.

Methods: After obtaining institutional review board approval, all patients requiring arterial line placement with documentation were included in this retrospective study between January 1, 2006, and December 31, 2012. Leveraging two robust data warehouses, the Perioperative DataMart and the Mayo Clinic Life Silences System, the authors cross-matched arterial line cannulation with a documented vascular consult, neurologic consult, infection, or return to surgery within 30 days in order to identify the initial patient population.

Results: A total of 62,626 arterial lines were placed in 57,787 patients, and 90.1% of the catheters placed were 20-gauge catheters. The radial artery was cannulated in 94.5% of patients. A total of 21 patients were identified as having experienced vascular complications or nerve injuries, resulting in a complication rate of 3.4 per 10,000 (95% CI, 2.1 to 5.1). Cardiac surgery had the largest number of catheters placed (n = 15,419) with 12 complications (complication rate = 7.8 per 10,000; 95% CI, 4.0 to 13.6). The rate of complications differed significantly ($P < 0.001$) across the three most common catheter sizes (2.7 per 10,000 [95% CI, 1.5 to 4.4] for 20 gauge, 17.2 per 10,000 [95% CI, 4.7 to 43.9] for 18 gauge, and 9.4 per 10,000 [95% CI, 1.1 to 34.1] for 5 French).

Conclusion: In a large retrospective study, the authors document a very low rate of complications with arterial line placement.
(ANESTHESIOLOGY 2016; 124:590-7)

ARTERIAL line cannulation is frequently used in the operating room and intensive care unit settings to provide easy access for continuous and real-time systemic blood pressure measurements, blood gas analysis, and other laboratory measurements.[1] Arterial cannulation provides invaluable hemodynamic information that aides practitioners in precise treatment of patients during the critical periods of care, but the benefit of the provided information does not come without risk. In humans, the use of arterial catheters can be traced back to 1949, with current widespread use throughout the United States and Europe totaling 8 million and 2.5 million placements, respectively.[2] Surgical and anatomical considerations are the influencing factors when choosing the site for arterial cannulation. Possible sites available for cannulation include the radial, brachial, axillary, femoral, ulnar, dorsalis pedis, posterior tibial, and temporal arteries.[3] The radial artery is the most common site for cannulation because it is thought to have a low rate of associated complications. This low rate of complication occurs as a result of extensive collateral circulation involving the ulnar artery and palmar arches with flow to the distal limb.[4] Complications associated with the arterial cannulation include temporary vascular occlusion, thrombosis, ischemia, hematoma formation, and local and catheter-related infection and sepsis.[2,3,5] Rarer complications associated with arterial cannulation include nerve damage and severe ischemia necessitating surgical

What We Already Know about This Topic

- Prior research has provided inconsistent data regarding the risk factors associated with arterial cannulation.
- The goal of the current study was to define the risks associated with arterial cannulation in order to prevent the potential development of vascular complications.

What This Article Tells Us That Is New

- In a series of 57,787 patients receiving arterial cannulation, 21 patients were identified as having experienced vascular complications or nerve injuries, resulting in a very low complication rate of 3.4 per 10,000. The rate of complications differed significantly ($P < 0.001$) across the three most common catheter sizes (2.7 per 10,000 for 20 gauge, 17.2 per 10,000 for 18 gauge, and 9.4 per 10,000 for 5 French). Given the low frequency of complications observed, the current study does not have sufficient statistical power to make definitive conclusions regarding risk factors (listed in the appendix).

Corresponding article on page 528.

Submitted for publication April 2, 2015. Accepted for publication October 22, 2015. From the Department of Anesthesiology, Mayo Clinic College of Medicine, Rochester, Minnesota.

amputation.[6] There are many risk factors that may contribute to these vascular complications.

Prior research has provided inconsistent data regarding the risk factors associated with arterial cannulation.[3,7–10] Due to the outdated and conflicting information provided by previous research, there is further need for a large-scale investigation into the risk factors associated with arterial line cannulation. The goal of our study was to clearly define the risks associated with arterial cannulation in order to prevent the potential development of vascular complications. Our hypothesis was that the factors such as diseases associated with arterial injury or atherosclerosis, catheter diameter size, catheter length, catheter composition or type, number of puncture attempts, and duration of arterial line in combination with arterial line cannulation are associated with an increased risk of an arterial and/or limb injury requiring consultation of a vascular surgeon, a neurologist, or need for surgery within 30 days.

Materials and Methods

After obtaining institutional review board approval, all patients requiring arterial line placement with documentation available in the Perioperative DataMart system at Mayo Clinic in Rochester, Minnesota, were included in this retrospective study between January 1, 2006, and December 31, 2012.

Since 2005, for all patients who had an arterial line placed in the operating room, a computerized form was filled out. This form included type of skin preparation, type of catheter placed and its size, site of catheter placement, patient position, use of ultrasound guidance and/or pressure transduction, catheter insertion depth, observations, and comments. The number of arterial line documents in the initial data pool was 77,388. The timeframe of data collection began at the time of arterial line insertion and ended at 30-day postline removal. Using two robust data warehouses, the Perioperative DataMart and the Mayo Clinic Life Silences System, we cross-matched arterial line cannulation with a documented vascular consult, neurologic consult, or return to surgery within 30 days in order to identify the initial patient population. After identification of a research population, chart reviewers (J.B., A.H., and S.K.) confirmed the accuracy of a diagnosis of vascular insult or neurologic compromise resulting from arterial cannulation. A review of 100 random negative charts was conducted in order to confirm the accuracy of the data pool. Patients who were identified with a vascular surgery consult or neurologic consult were subjected to a thorough chart review conducted to assess the presence of the above listed risk factors such as previous arterial injury, catheter diameter size, catheter length, catheter composition, number of puncture attempts, duration of arterial line, and coexisting diseases. To identify any infectious complications associated with arterial lines, we cross-matched our data with that in our infection surveillance program called Electronic Assisted Surveillance of Infection program.

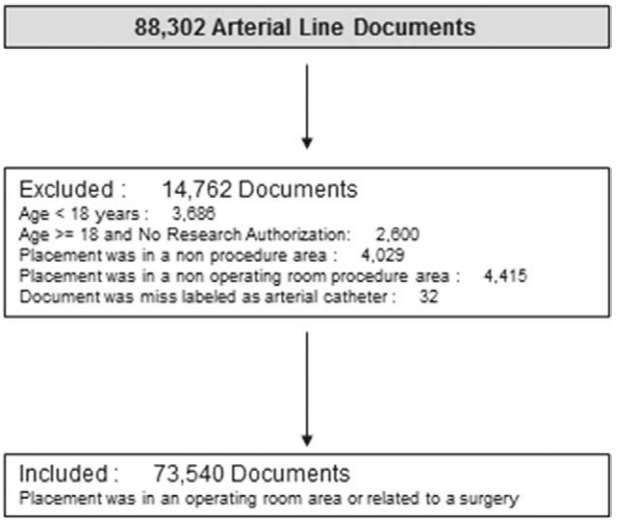

Fig. 1. Study flow diagram of arterial line.

Chart reviews were conducted only on those patients who provided a prior consent authorizing research to be performed on their medical records according to the Minnesota law. Patients under the age of 18 yr were also excluded (fig. 1). Patients who experienced line placement in a nonprocedure or nonoperating room area were excluded from our study. In total, 2,609 charts were individually reviewed for evaluation of a complication related to arterial line placement.

Data Analysis

Patient characteristics were summarized by using mean ± SD for continuous variables and frequency counts and percentages for categorical variables. For patients who underwent multiple surgeries during the study period, only the first surgery was included. However, since some patients had multiple arterial lines placed during surgery, the total number of arterial lines was greater than the total number of patients. The frequency of arterial line complications was calculated and expressed as the rate per 10,000 patients and also as the rate per 10,000 arterial lines. Rates were calculated overall and separately according to the type of procedure and summarized by using point estimates and exact 95% CIs. To assess whether the complication rate differed between radial *versus* femoral (and radial *vs.* brachial) in the same patients, an exact McNemar test was performed for the subset of patients who had both types of arterial lines placed for the same surgery. Conditional logistic regression was used to assess the patient characteristics potentially associated with arterial line complications. For these analyses, procedure type was included as the stratification variable. Findings from the conditional logistic regression analyses are summarized using the point estimate for the odds ratio (OR) along with 95% confidence limits. Due to the limited number of arterial line complications observed, we supplemented the traditional logistic regression approach with a Bayesian approach using data augmentation.[11,12] The Bayesian approach requires a "prior"

assumption about the effect of each risk factor on the outcome. Because little evidence is available for the risk factors assessed, for each risk factor, we specified a normal prior for β with a mean of 0 and variance of 2.0. A mean of 0 and variance of 2.0 for the prior distribution of β correspond to a prior median for the OR ($OR_{prior} = e^{\beta}$) of 1.0 indicating no association, and a prior 95% interval for the OR of that ranges from 0.0625 to 16.0. For the data augmentation approach, a prior data record for β is constructed so that fitting a no-intercept logistic regression model to this record would result in point and variance estimates that correspond to those specified for the prior. The prior data record is then added to the actual data records to construct the augmented data set. When this data set is analyzed by using logistic regression, the resulting OR estimate and corresponding 95% confidence limits are the approximate posterior median (OR_{post}) and corresponding 95% posterior limits.[11,12] Data were analyzed by using SAS software (SAS version 9.3; SAS Institute Inc., USA).

Results

A total of 77,388 arterial line documents were identified between January 1, 2006, and December 31, 2012, with 14,762 documents excluded as previously described (fig. 1). A total of 62,626 arterial lines were placed in 57,787 patients. The vast majority (90.1%) of the catheters placed were 20-gauge catheters. The majority of femoral catheters were either 15-cm 5-French catheters (44.7%) or 10-cm 18-gauge catheters (44.8%). Patients who had more than one line were included only once, and the first catheter placed was used. The demographics, disease comorbidities, and preoperative medications *versus* the site of arterial line placement are shown in table 1. The vast majority of arterial lines placed were in the radial artery (94.5%).

Upon review of the positive vascular consults, neurology consults, and returns to surgery documents in the 30-day postcatheter removal, a total of 21 complications were identified as related to arterial line placement. The majority of arterial lines were placed in cardiac surgery patients, and the majority of complications occurred in cardiac surgical patients (table 2). Of the related complications, 2 were in the brachial arterial lines (complication rate of 12.3 per 10,000 patients [95% CI, 1.5 to 44.4 per 10,000 patients]), 4 were in the femoral arterial lines (complication rate of 9.0 per 10,000 patients [95% CI, 2.4 to 22.9 per 10,000 patients]),

Table 1. Characteristics of Patients with Arterial Lines Placed during Surgery

		Type of Arterial Line*				
Characteristics	Overall (N = 58,787)	Radial (N = 55,774)	Femoral (N = 4,447)	Brachial (N = 1,617)	Ulnar (N = 395)	Others† (N = 173)
Demographics						
Age, mean ± SD	61.0 ± 16.1	61.1 ± 16.0	60.7 ± 17.4	59.9 ± 15.2	57.0 ± 16.3	58.1 ± 17.7
Male, n (%)	32,573 (55.4)	31,158 (55.9)	2,780 (62.5)	761 (47.1)	168 (42.5)	67 (38.7)
Comorbidities						
Congestive heart failure	2,680 (4.6)	2,415 (4.3)	542 (12.2)	104 (6.4)	27 (6.8)	5 (2.9)
Chronic kidney disease	5,405 (9.2)	4,915 (8.8)	773 (17.4)	267 (16.5)	46 (11.6)	20 (11.6)
Connective tissue disease	1,596 (2.7)	1,481 (2.7)	132 (3.0)	58 (3.6)	13 (3.3)	9 (5.2)
COPD	4,251 (7.2)	3,984 (7.1)	471 (10.6)	145 (9.0)	33 (8.4)	12 (6.9)
Cerebral vascular accident	3,733 (6.4)	3,469 (6.2)	460 (10.3)	117 (7.2)	23 (5.8)	11 (6.4)
Diabetes mellitus	15,232 (25.9)	14,397 (25.8)	1,253 (28.2)	504 (31.2)	96 (24.3)	37 (21.4)
Hypertension	29,201 (49.7)	27,687 (49.6)	2,362 (53.1)	785 (48.6)	187 (47.3)	84 (48.6)
Hyperlipidemia	24,268 (41.3)	23,039 (41.3)	2,181 (49.0)	567 (35.1)	148 (37.5)	66 (38.2)
Peripheral vascular disease	1,906 (3.2)	1,749 (3.1)	168 (3.8)	99 (6.1)	17 (4.3)	7 (4.0)
Coronary artery disease	11,131 (18.9)	10,412 (18.7)	1,380 (31.0)	327 (20.2)	93 (23.5)	36 (20.8)
Preoperative medications						
Aspirin	32,616 (55.5)	30,671 (55.0)	3,581 (80.5)	1,026 (63.4)	194 (49.1)	92 (53.2)
β-Blocker	28,655 (48.7)	26,789 (48.0)	3,693 (83.0)	864 (53.4)	201 (50.9)	82 (47.4
Calcium channel blocker	10,598 (18.0)	9,983 (17.9)	1,002 (22.5)	314 (19.4)	81 (20.5)	33 (19.1)
Diuretics	22,662 (38.6)	21,063 (37.8)	3,468 (78.0)	777 (48.0)	156 (39.5)	54 (31.2)
Statins	23,090 (39.3)	21,900 (39.3)	2,379 (53.5)	494 (30.6)	139 (35.2)	61 (35.3)
ACE inhibitors	16,413 (27.8)	15,354 (27.5)	1,886 (42.4)	375 (23.2)	120 (30.4)	44 (25.4)
Angiotensin receptor blocker	6,610 (11.2)	6,289 (11.3)	607 (13.6)	135 (8.4)	34 (8.6)	17 (9.8)
Coumadin	12,240 (20.8)	11,253 (20.2)	2,428 (54.6)	311 (19.2)	92 (23.3)	28 (16.2)
Heparin	6,391 (10.9)	5,941 (10.6)	611 (13.7)	258 (16.0)	52 (13.2)	18 (10.4)
Plavix	3,844 (6.5)	3,567 (6.4)	535 (12.0)	104 (6.4)	35 (8.9)	5 (2.9)

* A total of 62,626 arterial lines were placed in 58,787 patients. For the overall summary, patients who had multiple lines are included only once. For the line-type summaries, patients who had multiple arterial lines of different types (*e.g.*, radial + femoral) are included in the summary of each type they received. Patients who had multiple lines of the same type (bilateral radial, N = 197; bilateral femoral, N = 14; bilateral brachial, N = 8; and bilateral ulnar, N = 1) are included only once for the summary of the given line type. † Others include antecubital, axillary, pedal, and subclavian.

ACE = angiotensin-converting enzyme; COPD = chronic obstructive pulmonary disease.

Table 2. Frequency of Arterial Line Complications According to the Type of Procedure

	Per Arterial Line (N = 62,626)			Per Patient (N = 58,787)		
Procedure	N	Number of Complications	Rate per 10,000 Estimate (95% CI)	N	Number of Complications	Rate per 10,000 Estimate (95% CI)
Cardiac	15,419	12	7.8 (4.0–13.6)	12,407	12	9.7 (5.0–16.9)
General	14,961	4	2.7 (0.7–6.8)	14,886	4	2.7 (0.7–6.9)
Neuro	10,076	0	0.0 (0.0–3.7)	10,034	0	0.0 (0.0–3.7)
OBGyn	1,306	0	0.0 (0.0–28.2)	1,301	0	0.0 (0.0–28.3)
Orthopedic	5,156	1	1.9 (0.1–10.8)	5,135	1	1.9 (0.1–10.8)
Other	4,525	1	2.2 (0.1, 12.3)	4,417	1	2.3 (0.1–12.6)
Thoracic	4,187	1	2.4 (0.1–13.3)	4,174	1	2.4 (0.1–13.3)
Transplant	1,870	2	10.7 (1.3–38.6)	1,438	2	13.9 (1.7–50.2)
Urology	2,734	0	0.0 (0.0–13.5)	2,725	0	0.0 (0.0–13.5)
Vascular	2,392	0	0.0 (0.0–15.4)	2,270	0	0.0 (0.0–16.2)
Overall	62,626	21	3.4 (2.1–5.1)	58,787	21	3.6 (2.2–5.5)

A total of 62,626 arterial lines were placed in 58,787 patients.

NA = not applicable; Neuro = neurologic surgery; OBGyn = obstetric or gynecologic.

Table 3. Frequency of Complications According to the Type of Arterial Line and Type of Procedure*

	Radial		Femoral		Brachial		Ulnar		Others‡	
Procedure	N	Complications†	N	Complications†	N	Complications†	N	Complications†	N	Complications†
Cardiac	11,264	8 (7.1)	3,935	3 (7.6)	134	1 (74.6)	70	0 (0.0)	16	0 (0.0)
General	14,344	3 (2.1)	56	0 (0.0)	423	1 (23.6)	97	0 (0.0)	41	0 (0.0)
Neuro	9,799	0 (0.0)	28	0 (0.0)	136	0 (0.0)	84	0 (0.0)	29	0 (0.0)
OBGyn	1,247	0 (0.0)	0	NA	53	0 (0.0)	4	0 (0.0)	2	0 (0.0)
Orthopedic	4,924	1 (2.0)	27	0 (0.0)	146	0 (0.0)	34	0 (0.0)	25	0 (0.0)
Other	4,221	1 (2.4)	127	0 (0.0)	114	0 (0.0)	41	0 (0.0)	22	0 (0.0)
Thoracic	4,094	1 (2.4)	19	0 (0.0)	41	0 (0.0)	25	0 (0.0)	8	0 (0.0)
Transplant	1,217	1 (8.2)	137	1 (73.0)	485	0 (0.0)	13	0 (0.0)	18	0 (0.0)
Urology	2,686	0 (0.0)	9	0 (0.0)	25	0 (0.0)	11	0 (0.0)	3	0 (0.0)
Vascular	2,175	0 (0.0)	123	0 (0.0)	68	0 (0.0)	17	0 (0.0)	9	0 (0.0)
Overall	55,971	15 (2.7)	4,461	4 (9.0)	1,625	2 (12.3)	396	0 (0.0)	173	0 (0.0)
95% CI		(1.5–4.4)		(2.4–22.9)		(1.5–44.4)		(0.0–92.7)		(0.0–211.0)

* A total of 62,626 arterial lines were placed in 58,787 patients. Of 3,800 patients who had multiple lines placed, 3,091 had radial + femoral, 357 had radial + brachial, 220 had bilateral lines of the same type (197 bilateral radial, 14 bilateral femoral, 8 bilateral brachial, and 1 bilateral ulnar), and the rest had other combinations of line types. † Complications are expressed as number (rate per 10,000 arterial lines) with 95% CIs provided for the overall rate per 10,000 arterial lines. ‡ Others include antecubital, axillary, pedal, and subclavian.

Neuro = neurologic surgery; OBGyn = obstetric or gynecologic.

and 15 were in radial arterial lines (complication rate of 2.7 per 10,000 patients [95% CI, 1.5 to 4.4 per 10,000 patients]) (table 3). These differences were not statistically significant. A listing of complication by site of arterial catheter is provided in the appendix. Of note, only 11 of the 21 patients identified had a complication that required an intervention. The rate of complications differed significantly ($P < 0.001$) across the three most common catheter sizes (2.7 per 10,000 [95% CI, 1.5 to 4.4] for 20 gauge, 17.2 per 10,000 [95% CI, 4.7 to 43.9] for 18 gauge, and 9.4 per 10,000 [95% CI, 1.1 to 34.1] for 5 French). To further assess the association between catheter size and complications, a conditional logistic regression analysis was performed with site (radial/brachial/femoral) as the stratification variable. From this analysis, the risk for complication was found to be significantly ($P = 0.029$) associated with catheter size (OR, 8.0; 95% CI, 1.7 to 37.1 for 18 gauge *vs.* 20 gauge but not for 5 French *vs.* 20 gauge, OR, 5.9; 95% CI, 0.5 to 63.8).

Among 3,091 patients who had both radial and femoral lines placed during the same procedure, there were 6 patients who developed complications (4 femoral arterial line complications *vs.* 2 radial arterial line complications; McNemar test exact $P = 0.688$). Among 357 patients who had both radial and brachial lines placed during the same procedure, there was 1 patient who developed a complication (1 radial line complication *vs.* 0 brachial line complications; McNemar test exact $P = 1.0$).

Patient characteristics potentially associated with arterial line complications are listed in table 4. From the standard conditional logistic regression analysis, male sex was protective ($P = 0.046$) and preoperative use of clopidogrel was associated with increased risk ($P = 0.033$). A history

Table 4. Patient Characteristics Potentially Associated with Arterial Line Complications*

	Complication Rate in Those with and without Risk Factor		Conditional Logistic Regression Results†		
			Standard Approach		Bayesian Approach
Risk Factors	With	Without	OR (95% CI)	*P* Value	OR (95% CI)
Demographics					
Male	8/32,573	13/26,214	0.41 (0.16–0.99)	0.046	0.46 (0.20–1.04)
Comorbidities					
Congestive heart failure	0/2,680	21/56,107	0.00 (-, 1.37)	0.092	0.44 (0.07–1.93)
Chronic kidney disease	3/5,405	18/53,382	1.03 (0.23–3.24)	0.968	1.02 (0.30–2.87)
Connective tissue disease	2/1,596	19/57,191	3.70 (0.59–12.82)	0.138	2.40 (0.50–8.19)
COPD	2/4,251	19/54,536	1.30 (0.21–4.51)	0.732	1.20 (0.29–3.70)
Cerebral vascular accident	4/3,733	17/55,054	3.09 (0.88–8.43)	0.074	2.46 (0.78–6.46)
Diabetes mellitus	6/15,232	15/43,555	1.02 (0.36–2.50)	0.974	1.01 (0.40–2.35)
Hypertension	9/29,201	12/29,586	0.68 (0.28–1.62)	0.384	0.72 (0.31–1.60)
Hyperlipidemia	11/24,268	10/34,519	1.29 (0.54–3.13)	0.570	1.25 (0.55–2.84)
Peripheral vascular disease	0/1,906	21/56,881	0.00 (-, 2.86)	0.239	0.58 (0.08–2.97)
Coronary artery disease	7/11,131	14/47,656	1.67 (0.62–4.09)	0.294	1.55 (0.62–3.58)
Preoperative medications					
Aspirin	12/32,616	9/26,171	0.61 (0.24–1.62)	0.315	0.66 (0.28–1.62)
β-Blocker	13/28,655	8/30,132	0.71 (0.26–2.04)	0.521	0.76 (0.30–1.97)
Calcium channel blocker	4/10,598	17/48,189	0.83 (0.24–2.28)	0.735	0.86 (0.29–2.16)
Diuretics	14/22,662	7/36,125	1.84 (0.72–5.16)	0.209	1.68 (0.70–4.20)
Statins	9/23,090	12/35,697	0.83 (0.33–2.04)	0.691	0.86 (0.36–1.96)
ACE inhibitors	5/16,314	16/42,473	0.62 (0.20–1.61)	0.340	0.67 (0.25–1.61)
Angiotensin receptor blocker	4/6,610	17/52,177	1.66 (0.48–4.48)	0.391	1.50 (0.50–3.82)
Coumadin	9/12,240	12/46,547	1.54 (0.58–4.00)	0.376	1.44 (0.59–3.47)
Heparin	4/6,391	17/52,396	1.93 (0.55–5.31)	0.271	1.70 (0.55–4.39)
Plavix	5/3,844	16/54,943	3.50 (1.12–9.29)	0.033	2.79 (0.96–7.07)

* A total of 21 arterial line–related complications were observed among 58,787 patients who had one or more arterial lines placed during surgery. † Due to the limited number of arterial line complications, risk factors were assessed using a standard conditional logistic regression approach and also using a Bayesian approach. For the Bayesian approach, we specified a prior mean β of 0 (OR = e^{β} = 1.0 indicating no association) with a variance of 2.0 (OR 95% CI, 1/16 to 16).

ACE = angiotensin-converting enzyme; COPD = chronic obstructive pulmonary disease; OR = odds ratio.

of connective tissue disease and cerebral vascular accident were associated with increased risk, but this was not statistically significant. When a Bayesian approach was used, the confidence bounds for the OR contained 1.0 for all of the characteristics assessed. This suggests that the statistically significant findings from the standard analysis may be questionable given the small number of complications observed.

There were 14 patients who developed the line-associated infection due to their arterial line, resulting in an overall infection rate of 2.4 per 10,000 patients (95% CI, 1.3 to 4.0 per 10,000 patients). Line-associated infections were positive catheter tip cultures on surveillance cultures. For the patients who developed infections, all of the arterial lines were placed in the radial artery. Five of the patients had a tracheostomy performed as their surgery, five of the patients underwent a laparotomy, and four of the patients underwent cardiac surgery.

Discussion

The goal of our study was to clearly define the risks associated with arterial cannulation in order to prevent the potential development of vascular complications. The majority of the catheters placed were of only three types. From conditional logistic regression, stratified by catheter site, the likelihood of complications was found to be increased with the larger catheters *versus* the 20-gauge catheters. At our institution, we tend to put the larger catheters in the femoral site. Although not statistically significant, the radial arterial line site had the lowest rate of complications and the femoral had the highest. We found some evidence to suggest that female sex and preoperative use of clopidogrel were potential predictors of arterial line complications. However, given the low number of complications observed, and the confidence bounds for the OR from the Bayesian analysis, these findings should be considered exploratory. Overall, we document a low rate of complications associated with arterial line placement.

Prior research has provided inconsistent data regarding the risk factors associated with arterial cannulation.[3,7–10] A study conducted by Hoencamp *et al.*[7] focused on examining the possible damaging effects of arterial monitoring catheters on arterial functioning in critical care patients after elective surgical procedures. The study looked at 23 patients with an arterial catheter, using the noncannulated arm as a control and using the radial-to-ulnar ratio for the assessment of

arterial functioning. The radial-to-ulnar ratio was defined as the radial artery systolic pressure divided by the ulnar artery systolic pressure. The study concluded that there is a significant change in the hemodynamic functioning of the cannulated arteries 1 day and 5 days after arterial line removal, with the significant change decreasing and disappearing 30 days after line removal. The authors' conclusion was that arterial catheterization on a short-term basis is a safe procedure.

A study by Wilkins[13] found that emboli originating from a proximal site, excessive trauma resulting from large-bore cannulae, prolonged shock, hyperlipoproteinemia, or prior vascular disease are contributing factors to the onset of tissue necrosis.

A study conducted by Slogoff *et al.*[9] examined the safety of radial cannulation during a 4-month period of time on adult patients scheduled for elective operations requiring radial arterial cannulation at the Texas Heart Institute, 1,699 cardiovascular surgical patients and in 83 patients in whom cannulation was performed in another artery after failure at the radial site. The study indicated that the incidence of abnormal radial arterial flow was related neither to the duration of cannulation nor to the size or material of the cannula. Hematoma and female sex were the only factors found to significantly increase the incidence of abnormal radial flow. Abnormal flow was found early in the study in 21.2% of participants, but sensory abnormalities and other vascular complications only occurred in 0.6% of all cases. They showed, as do we, that arterial lines have a very low rate of complications and female sex is a risk factor for complications.

Lipira *et al.*[8] published a case report and literature review in May 2010 discussing hand ischemia and axillary arterial catheter use. The case reported involved many factors including hypothermia, a female patient, and a trauma involving long-bone fractures. Frezza and Mezghebe[14] performed a retrospective comparison of 4,392 in surgical and medical intensive care unit patients with arterial catheters. This study found that the most common complication were "vascular insufficiency," bleeding, and infection. A prospective study by Scheer *et al.*[3] found that axillary catheters have a lower rate of obstruction, ischemia, and thrombosis than radial catheters. Risk factors listed by Lipira *et al.* were the use of vasopressors, previous injury to the artery, duration of cannulation (over 48 or 72 h), hematoma, disseminated intravascular coagulation, reduced cardiac output, and the female sex. Our study was not able to address many of these risk factors except size of the catheter and female sex.

How does our complication rate compare with those in the cardiac catheterization laboratory because the cardiologists cannulate either the radial or femoral arteries for angiography and percutaneous coronary intervention (PCI)? There are two meta-analyses of randomized trials comparing radial to femoral access for angiography and PCI. Jolly *et al.*[15] demonstrated a major bleeding in 0.05% for radial access and 2.3% for femoral access. Another study by Jolly *et al.*[16] found major vascular complications in 1.4% of radial cannulations and 3.7% of femoral cannulations. Minor bleeding occurred in 2.9% of radial cannulations and 3.4% of femoral cannulations. It should be noted that the cannulas used for angiography and PCI are larger than those used in the operating room, and the patients frequently are on antiplatelet agents after PCI. Furthermore, cardiologists often use specific vascular closure devices, which may result in complications.

There are limitations to our study. Our initial intention was to look at the number of arterial cannulation attempts and the duration of catheter placement as predictors of adverse outcomes. We were not able to capture these data. Our outcome measures are designed to detect only major complications. We were not able to detect minor complications such as transient neurologic symptoms. We also did not look at the complications of arterial line placement outside of the operating room. Also, given the low frequency of complications observed, our study does not have sufficient statistical power to make definitive conclusions regarding the risk factors.

In a very large retrospective study of prospectively collected data, we found that larger arterial catheters had a higher complication rate than 20-gauge catheters. We also document a very low rate of complications overall with arterial line placement.

Acknowledgments

All financial and material support for the research and work described in this article is received from the Department of Anesthesiology, Mayo Clinic College of Medicine, Rochester, Minnesota.

Competing Interests

The authors declare no competing interests.

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Appendix: A Description of Patient Complications Arranged by the Site of Arterial Line Placement

Patient Age/Sex	Surgical Procedure	Catheter Size/Site	Complications	Management/Outcome
81 yr old/male	Tricuspid valve repair	20 gauge/brachial	Hand pain and swelling, occlusion of brachial, radial, and ulnar arteries by Doppler study	Brachial artery cut down, embolectomy with patch repair/patient improved
65 yr old/female	Abdominal exploration for necrotic ilium	20 gauge/brachial	Cool cyanotic hand, ultrasound revealed nonocclusive thrombus in radial artery	IV heparin therapy/patient improved
65 yr old/female	Heart and liver transplant	5 French 15 cm/femoral	Dusky toes	Arterial line remove/patient improved
84 yr old/male	Aortic valve replacement	5 French 15 cm/femoral	Cool, dusky leg, ultrasound showed downstream ischemia and proximal stenosis	Arterial line remove/patient improved
84 yr old/male	Coronary artery bypass	18 gauge 10 cm/femoral	No pulses distal to popliteal artery, ultrasound showed no flow	Thrombectomy and fasciotomy, skin graphing/patient improved
80 yr old/female	Aortic valve replacement and coronary artery bypass	18 gauge 10 cm/femoral	Cool pulseless leg noted in emergency department for cerebral vascular accident	IV heparin infusion started, but the patient died of cerebral vascular accident
74 yr old/female	Mitral valve replacement and coronary artery bypass	20 gauge/radial	Hand pain, ultrasound showed radial artery thrombus	Embolectomy/patient improved
76 yr old/female	Aortic and mitral valve replacement	20 gauge/radial	Decreased pulses, ultrasound showed brachial, radial, and ulnar occlusion	Embolectomy and fasciotomy/patient improved
75 yr old/female	Coronary artery bypass	20 gauge/radial	Numb hand, ultrasound showed normal vessels, electromyography showed median and ulnar nerve neuropathy	Arterial line remove/patient improved
72 yr old/female	Exploratory laparotomy, extensive lysis of adhesions	20 gauge/radial	Cool hand, ultrasound was normal	Arterial line remove/patient improved
43 yr old/female	Laparoscopic sleeve gastrectomy	20 gauge/radial	Cool hand, ultrasound showed radial artery thrombus	Arterial line remove/patient improved
48 yr old/female	Laparoscopic Roux-en-Y gastric bypass	20 gauge/radial	Loss of pulse and wrist pain after arterial line removal	Resolved on its own
75 yr old/male	Thoracotomy, right upper lobectomy	20 gauge/radial	Cooled mottled hand with pressure after arterial line removal	Resolved on its own
62 yr old/male	Orthotopic liver retransplantation	20 gauge/radial	Loss of pulse and occluded radial artery on ultrasound	Pulse returned/no further therapy required
34 yr old/female	Mitral valve replacement	18 gauge/radial	Wrist pain, occlusive thrombus in the radial artery on ultrasound	Open thrombectomy/patient improved
64 yr old/male	Mitral, tricuspid, and aortic valve replacement, intraaortic balloon pump	20 gauge/radial	Loss of pulse, occluded brachial, radial, and ulnar artery on ultrasound	Heparin-induced thrombocytopenia type II, fasciotomy of arm and hand/patient improved
66 yr old/female	Decompression and fusion of lower thoracic and lumbar spine	20 gauge/radial	Loss of pulse	Heparin-induced thrombocytopenia type II, embolectomy, argatroban infusion/patient improved
74 yr old/male	Coronary artery bypass	20 gauge/radial	Loss of pulse	Angiography, thrombolytic infusion in radial artery/patient improved
21 yr old/female	Pulmonary thromboendarterectomy, extracorporeal membrane oxygenation	20 gauge/radial	Loss of pulse, radial artery thrombosis on ultrasound	Antiphospholipid antibody syndrome, heparin-induced thrombocytopenia type II, argatroban infusion/patient improved
64 yr old/female	left ventricular septal myomectomy	20 gauge/radial	Wrist and hand pain, radial artery occlusion on ultrasound	IV heparin infusion/patient improved
65 yr old/male	Coronary artery bypass	20 gauge/radial	Difference in blood pressure between arms, ultrasound showed radial occlusion	Asymptomatic, no therapy